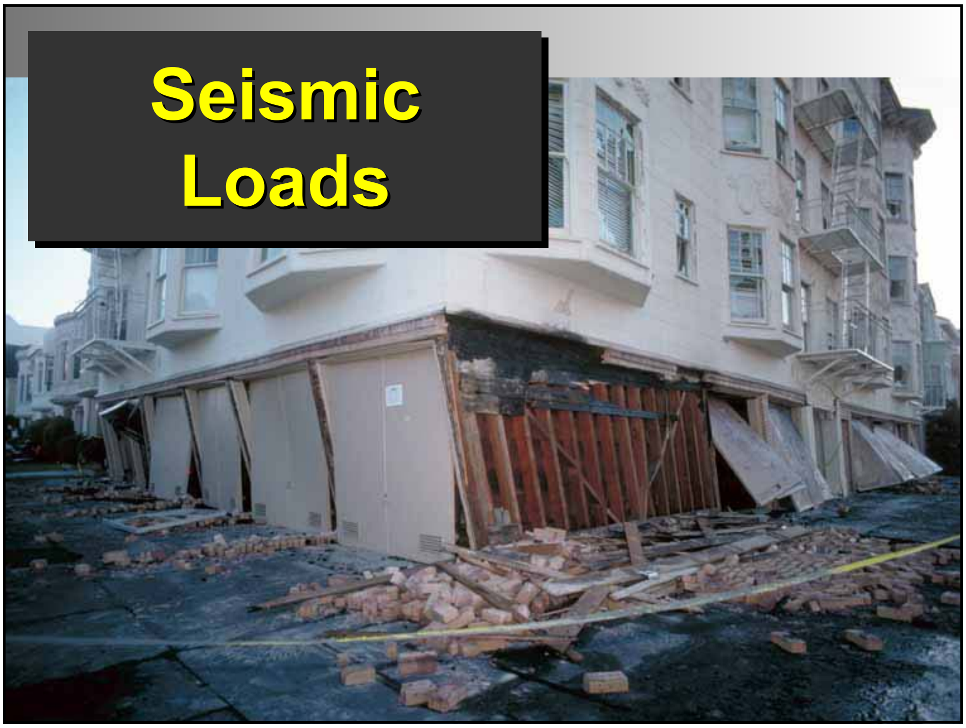
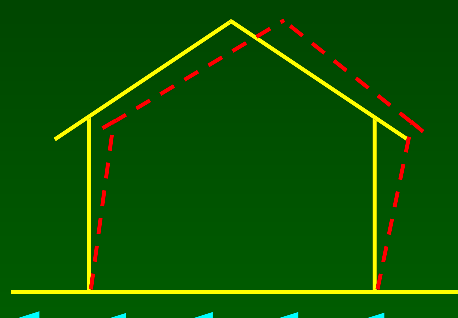
Seismic Loads



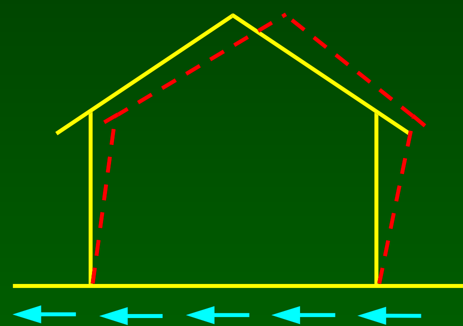
Background

- Earthquake forces are lateral forces
- Ground moves suddenly horizontally (also vertically)
- Inertia of the building tries to keep it from moving



Background

- Resulting force on the building can be simplified to be a lateral force - a shearing force on the base of the structure
- Force depends on:
  - earthquake intensity
  - soil conditions
  - stiffness of building



Determining Seismic Forces

- ASCE 7 serves as the basis for calculating seismic forces
- We'll use the Standard Building Code
  - methods in SBC limited to buildings < 35 ft high
- Methods determine:
  - seismic forces on members and connections
  - story drift

Seismic Design

- Complete design checks:
  - vertical distribution of shear forces
  - horizontal distribution of shear forces
  - overturning moment
  - story drift

- **Equivalent Base Shear** calculated by (1999 Standard Building Code):

$$V = C_S W$$

- V = equivalent shear force acting on the base of the structure (lbs)
- C_S = seismic design coefficient
- W = total dead load of the building (lbs)

- **Seismic Design Coefficient** C_s:

$$C_S = \frac{1.2\ A_V\ S}{R\ T^{\frac{2}{3}}}$$

- A_V = coefficient for peak velocity related acceleration
- S = coefficient for soil profile characteristics of the site
- R = response modification factor
- T = fundamental period of the building

- **Design Step 1**:
- **Document the required design data:**
  - **Building location**
  - **Use of building - exposure**
  - **Site conditions**
  - **Type of structure**
  - **Type of analysis method used**

- **Design Step 2**:
- **Find Av and Aa**
  - **See Figure 1607.1.5A**
  - **See Figure 1607.1.5B**

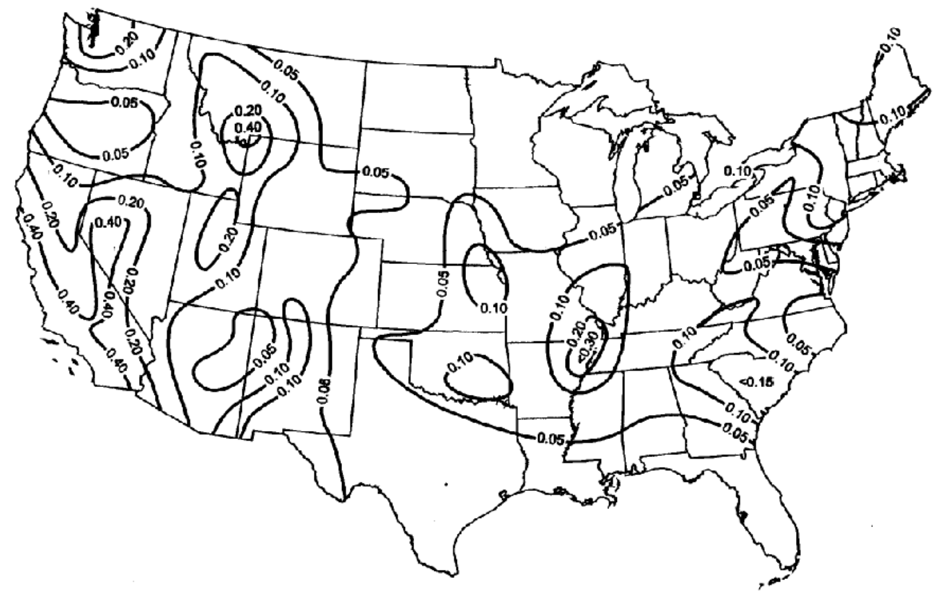


FIGURE 1607.1.5A
CONTOUR MAP OF EFFECTIVE PEAK VELOCITY-RELATED ACCELERATION COEFFICIENT, A_V

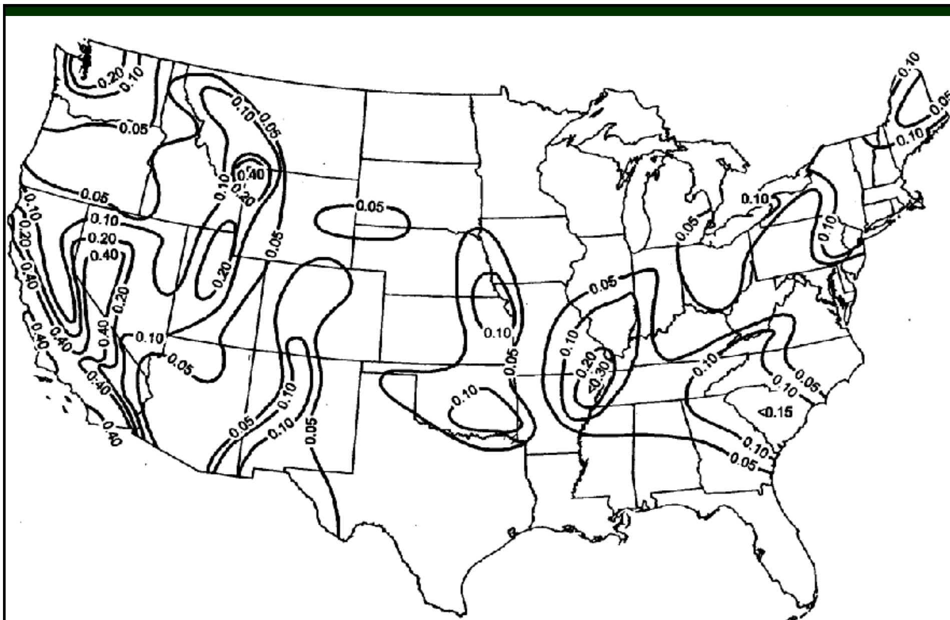


FIGURE 1607.1.5B
CONTOUR OF PEAK ACCELERATION COEFFICIENT, A_a

- **Design Step 3:**

- **Find the Seismic Hazard Exposure Group**
  - **See Table 1607.1.6 for the classification of the building**

TABLE 1607.1.6
SEISMIC HAZARD EXPOSURE GROUP

GROUP TYPE	NATURE OF OCCUPANCY
Group I	All buildings except those listed below
Group II Seismic Hazard Exposure Group II buildings are those which have a substantial public hazard due to occupancy or use, including buildings containing any one or more of the indicated uses.	1. Group A in which more than 300 people congregate in one room. 2. Group E with an occupant load greater than 250. 3. Group B used for college or adult education with an occupant load greater than 500. 4. Group I Unrestrained with an occupant load greater than 50, not having surgery or emergency treatment facilities. 5. Group I Restrained. 6. Power generating stations and other public utility facilities not included in Group III Seismic Hazard Exposure Group. 7. Any other occupancy with an occupant load greater than 5,000.
Group III Seismic Hazard Exposure Group III buildings are those having essential facilities which are required for postearthquake recovery, including buildings containing any one or more of the indicated uses.	1. Fire or rescue and police stations. 2. Group I Unrestrained having surgery or emergency treatment facilities. 3. Earthquake emergency preparedness centers. 4. Postearthquake recovery vehicle garages. 5. Power generating stations and other utilities required as emergency backup facilities. 6. Primary communication facilities. 7. Highly toxic materials as defined by 308.2.1 as an H4 occupancy where the quantity of the material exceeds the exempt amounts of Table 308.2D.

- **Design Step 4:**

- Find the Seismic Performance Category
  - See Table 1607.1.8 for the performance category

TABLE 1607.1.8
SEISMIC PERFORMANCE CATEGORIES

EFFECTIVE PEAK VELOCITY-RELATED ACCELERATION, A_v	SEISMIC HAZARD EXPOSURE GROUP I	II	III
$A_v < 0.05$	A	A	A
$0.05 \le A_v < 0.10$	B	B	C
$0.10 \le A_v < 0.15$	C	C	C
$0.15 \le A_v < 0.20$	C	D	D
$0.20 \le A_v$	D	D	E

- **Design Step 5**:

- Find the Site Coefficient
  - See Table 1607.3.1 for the site coefficient
  - Use 2.0 if you don't have information
  - Make sure you do the site investigation to know the soil characteristics

TABLE 1607.3.1
SITE COEFFICIENT

SOIL PROFILE TYPE	DESCRIPTION	SITE COEFFICIENT S
S_1	A soil profile with either: Rock of any characteristic, either shale-like or crystalline in nature, which has a shear wave velocity greater than 2,500 feet per second or Stiff soil conditions where the soil depth is less than 200 feet and the soil types overlaying rock are stable deposits of sands, gravels or stiff clays.	1.0
S_2	A soil profile with deep cohesionless or stiff clay conditions, where the soil depth exceeds 200 feet and soil types overlaying rock are stable deposits of sands, gravels, or stiff clays.	1.2
S_3	A soil profile containing 20 to 40 ft in thickness of soft to medium-stiff clays with or without intervening layers of cohesionless soils.	1.5
S_4	A soil profile characterized by a shear wave velocity of less than 500 feet per second containing more than 40 ft of soft clay.	2.0

- **<u>Design Step 6</u>:**

- **Find the Response Modification Factor, R**
  - **See Table 1607.3.3**
- **Find the Deflection Amplification Factor, C_d**
  - **See Table 1607.3.3**

TABLE 1607.3.3[1]
STRUCTURAL SYSTEMS

BASIC STRUCTURAL SYSTEM Seismic resisting system	RESPONSE MODIFICATION FACTOR R	DEFLECTION AMPLIFICATION FACTOR C_d	STRUCTURAL SYSTEM LIMITATIONS AND BUILDING HEIGHT (ft) LIMITATIONS[2] Seismic Performance Category A & B	C	D[4]	E[5]
BEARING WALL SYSTEM						
Light framed walls w/shear panels	6 1/2	4	NL	NL	160	100
Reinforced concrete shear walls	4 1/2	4	NL	NL	160	100
Reinforced masonry shear walls	3 1/2	3	NL	NL	160	100
Concentrically braced frames	4	3 1/2	NL	NL	160	100
Unreinforced masonry shear walls	1 1/4	1 1/4	NL	Note 3	NP	NP
Plain Concrete Shear Walls	1 1/2	1 1/2	NL	Note 3	NP	NP
BUILDING FRAME SYSTEM						
Eccentrically braced frames, moment resisting connections at columns away from link beam	8	4	NL	NL	160	100
Eccentrically braced frames, non-moment resisting connections at columns away from link beam	7	4	NL	NL	160	100
Light framed walls with shear panels	7	4 1/4	NL	NL	160	100
Concentrically braced frames	5	4 1/2	NL	NL	160	100
Reinforced concrete shear walls	5 1/2	5	NL	NL	160	100
Reinforced masonry shear walls	4 1/2	4	NL	NL	160	100
Unreinforced masonry shear walls	1 1/2	1 1/2	NL	Note 3	NP	NP
Plain Concrete Shear Walls	2	2	NL	Note 3	NP	NP
MOMENT RESISTING FRAME SYSTEM						
Special moment frames of steel	8	5 1/2	NL	NL	NL	NL
Special moment frames of reinforced concrete	8	5 1/2	NL	NL	NL	NL
Intermediate moment frames of reinforced concrete	5	4 1/2	NL	NL	NP	NP
Ordinary moment frames of steel	4 1/2	4	NL	NL	160	100
Ordinary moment frames of reinforced concrete	3	2 1/2	NL	NP	NP	NP
DUAL SYSTEM WITH A SPECIAL MOMENT FRAME CAPABLE OF RESISTING AT LEAST 25% OF THE PRESCRIBED SEISMIC FORCES						
Eccentrically braced frames, moment resisting connections at columns away from link beam	8	4	NL	NL	NL	NL
Eccentrically braced frames non-moment resisting connections at columns away from link beam	7	4	NL	NL	NL	NL
Concentrically braced frames	6	5	NL	NL	NL	NL
Reinforced concrete shear walls	8	6 1/2	NL	NL	NL	NL
Reinforced masonry shear walls	6 1/2	5 1/2	NL	NL	NL	NL
Wood sheathed shear walls	8	5	NL	NL	NL	NL
DUAL SYSTEM WITH AN INTERMEDIATE MOMENT FRAME OF REINFORCED CONCRETE OR AN ORDINARY MOMENT FRAME OF STEEL CAPABLE OF RESISTING AT LEAST 25% OF THE PRESCRIBED SEISMIC FORCES						
Concentrically braced frames	5	4 1/2	NL	NL	160	100
Reinforced concrete shear walls	6	5	NL	NL	160	100
Reinforced masonry shear walls	5	4 1/2	NL	NL	160	100
Wood sheathed shear walls	7	4 1/2	NL	NL	160	100
INVERTED PENDULUM STRUCTURES						
Special moment frames of structural steel	2 1/2	2 1/2	NL	NL	NL	NL
Special moment frames of reinforced concrete	2 1/2	2 1/2	NL	NL	NL	NL
Ordinary moment frames of structural steel	1 1/4	1 1/4	NL	NL	NP	NP

For SI: 1 ft = 0.305 m.

NL = not limited
NP = not permitted

Notes:

1. Response modification Factor R for use in 1607.4 and 1607.5. Deflection amplification factor C_d for use in 1607.4 and 1607.5.
2. The building height is not to exceed the general height limitation of Table 500 based on the type of construction.
3. The masonry shear walls shall have nominal reinforcement as required by Section 10.5 of ACI 530/ASCE 5/TMS 402. See 2115.2.
4. See 1607.3.3.4.1 for description of building systems which are limited to buildings with a height of 240 ft or less.
5. See 1607.3.3.5 for description of building systems which are limited to buildings with a height of 160 ft or less.

TABLE 1607.3.3[1]
STRUCTURAL SYSTEMS

BASIC STRUCTURAL SYSTEM Seismic resisting system	RESPONSE MODIFICATION FACTOR R	DEFLECTION AMPLIFICATION FACTOR C_d	STRUCTURAL SYSTEM LIMITATIONS AND BUILDING HEIGHT (ft) LIMITATIONS[2] Seismic Performance Category A & B	C	D[4]	E[5]
BEARING WALL SYSTEM						
Light framed walls w/shear panels	6 1/2	4	NL	NL	160	100
Reinforced concrete shear walls	4 1/2	4	NL	NL	160	100
Reinforced masonry shear walls	3 1/2	3	NL	NL	160	100
Concentrically braced frames	4	3 1/2	NL	NL	160	100
Unreinforced masonry shear walls	1 1/4	1 1/4	NL	Note 3	NP	NP
Plain Concrete Shear Walls	1 1/2	1 1/2	NL	Note 3	NP	NP
BUILDING FRAME SYSTEM						
Eccentrically braced frames, moment resisting connections at columns away from link beam	8	4	NL	NL	160	100
Eccentrically braced frames, non-moment resisting connections at columns away from link beam	7	4	NL	NL	160	100
Light framed walls with shear panels	7	4 1/4	NL	NL	160	100
Concentrically braced frames	5	4 1/2	NL	NL	160	100
Reinforced concrete shear walls	5 1/2	5	NL	NL	160	100
Reinforced masonry shear walls	4 1/2	4	NL	NL	160	100
Unreinforced masonry shear walls	1 1/2	1 1/2	NL	Note 3	NP	NP
Plain Concrete Shear Walls	2	2	NL	Note 3	NP	NP
MOMENT RESISTING FRAME SYSTEM						
Special moment frames of steel	8	5 1/2	NL	NL	NL	NL
Special moment frames of reinforced concrete	8	5 1/2	NL	NL	NL	NL
Intermediate moment frames of reinforced concrete	5	4 1/2	NL	NL	NP	NP
Ordinary moment frames of steel	4 1/2	4	NL	NL	160	100
Ordinary moment frames of reinforced concrete	3	2 1/2	NL	NP	NP	NP

- **Design Step 7**:
- **Calculate the Fundamental Period of the building, T**
  - **T is from an analysis of the structural properties of the building elements**
  - **to estimate T, we use:**

$$T = T_a C_a$$

- Calculate the Fundamental Period of the building, T

$$T = T_a C_a$$

$$T_a = C_T (h_n)^{\frac{3}{4}}$$

- C_T = 0.02 for wood framed buildings with shear walls
- h_n = height of building
- C_a is from Table 1607.4.1.2

TABLE 1607.4.1.2
COEFFICIENT FOR UPPER LIMIT ON CALCULATED PERIOD, C_a

A_v COEFFICIENT REPRESENTING EFFECTIVE PEAK VELOCITY-RELATED ACCELERATION	C_a
0.4	1.2
0.3	1.3
0.2	1.4
0.15	1.5
0.1	1.7
0.05	1.7

- **Design Step 8:**
- Calculate Seismic Design Coefficient C_s:

$$C_S = \frac{1.2\ A_V\ S}{R\ T^{\frac{2}{3}}}$$

- C_s need not be less than:

$$C_S = \frac{2.5\ A_a}{R}$$

- **Design Step 9:**
- Calculate Dead Load of the Building, W
  - Estimate weights of all building materials and permanent fixtures
    - HVAC, plumbing, etc.

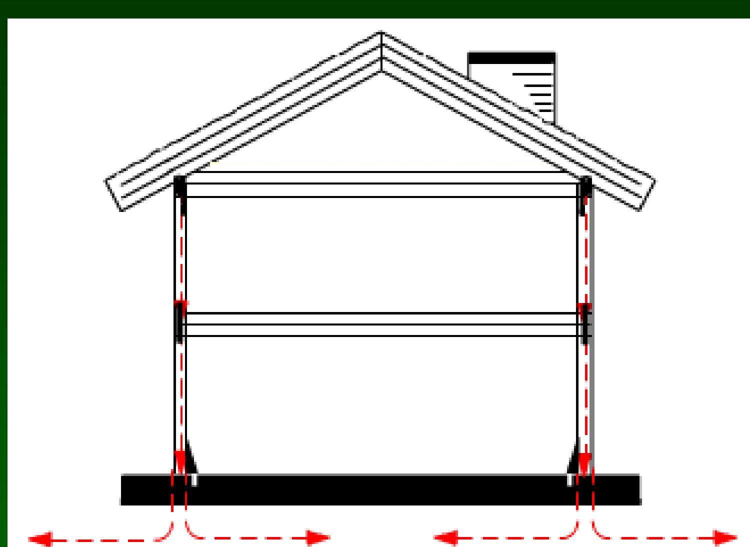
- **Design Step 10:**
- Calculate base shear force:

$$V = C_s W$$

- **Other Steps:**
- Calculate vertical distribution of shear forces
- Calculate horizontal distribution of shear forces at each story
  - depends on relative stiffness of each vertical structural element
  - Check torsion in building

- **Other Steps:**
- Find overturning moments
- Calculate story drift and compare against the allowable drift
- Check building stability

Continuous Load Path



Determining Deflection Criteria

- Deflection is the main serviceability concern in structures
  - Excessive deflection in floors and roofs makes occupants feel uncomfortable
  - Excessive deflection leads to cracked ceilings, cracked walls, cracked bridge surfaces

Deflection Criteria

- Deflection criteria for buildings are found in Standard Building Code (and many other design references)

TABLE 1610.1
DEFLECTION LIMITS[1, 2, 3, 4, 5]

CONSTRUCTION	LL	DL + LL
Roof member supporting plaster, or floor member	L/360	L/240
Roof members supporting nonplastered ceilings	L/240	L/180
Roof members not supporting ceilings	L/180	L/120
Exterior and interior walls and partitions with brittle finishes	L/240	–
Exterior and interior walls and partitions with flexible finishes	L/120	–
Farm buildings	–	L/180
Greenhouses	–	L/120

LL = Live load
DL = Dead load
L = Length of member in same units as deflection

Deflection Criteria

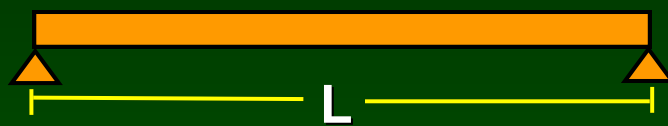


TABLE 1610.1
DEFLECTION LIMITS[1, 2, 3, 4, 5]

CONSTRUCTION	LL	DL + LL
Roof member supporting plaster, or floor member	L/360	L/240
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Roof members not supporting ceilings	L/180	L/120
Exterior and interior walls and partitions with brittle finishes	L/240	–
Exterior and interior walls and partitions with flexible finishes	L/120	–
Farm buildings	–	L/180
Greenhouses	–	L/120

LL = Live load
DL = Dead load
L = Length of member in same units as deflection

Load Combinations

- **Don't forget to apply load combinations in design**

SECTION 1609
LOAD COMBINATIONS

1609.1 Allowable stress design. Every building element shall be provided with sufficient strength to resist the most critical effects resulting from the following combinations of loads:

1. Dead Load + Floor Live[1] + Roof Live (or Snow)[2]
2. Dead Load + Floor Live[1] + Wind (or Seismic/1.4)
3. Dead Load + Floor Live[1] + Wind + 1/2 Snow[2]
4. Dead Load + Floor Live[1] + 1/2 Wind + Snow[2]
5. Dead Load + Floor Live[1] + Snow[3] + Seismic/1.4

Notes:

1. Floor live load shall not be included where its inclusion results in lower stresses in the building element under investigation.
2. Crane loads need not be combined with roof live load nor with more than 3/4 of snow load or 1/2 wind load.
3. Snow loads over 30 psf (1.44 kPa) may be reduced no more than 80% upon approval of the building official. Snow loads 30 psf (1.44 kPa) or less need not be combined with seismic.

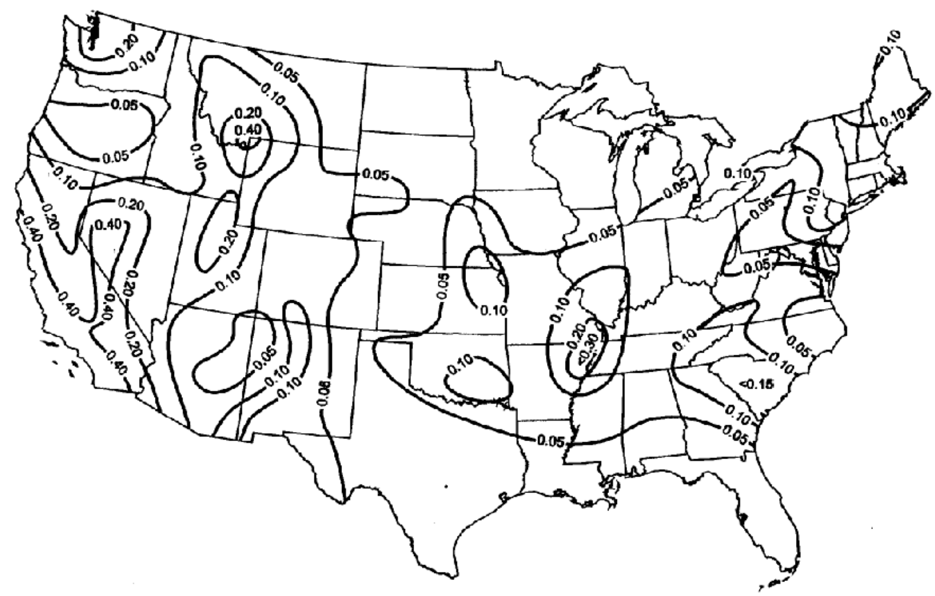

FIGURE 1607.1.5A
CONTOUR MAP OF EFFECTIVE PEAK VELOCITY-RELATED ACCELERATION COEFFICIENT, A_V

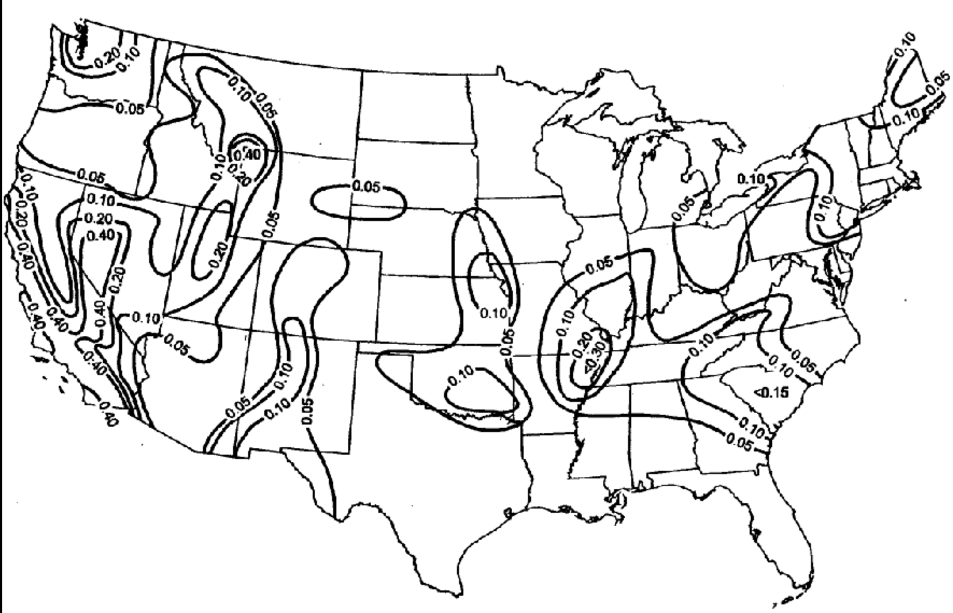

FIGURE 1607.1.5B
CONTOUR OF PEAK ACCELERATION COEFFICIENT, A_a

TABLE 1607.1.6
SEISMIC HAZARD EXPOSURE GROUP

GROUP TYPE	NATURE OF OCCUPANCY
Group I	All buildings except those listed below
Group II Seismic Hazard Exposure Group II buildings are those which have a substantial public hazard due to occupancy or use, including buildings containing any one or more of the indicated uses.	1. Group A in which more than 300 people congregate in one room. 2. Group E with an occupant load greater than 250. 3. Group B used for college or adult education with an occupant load greater than 500. 4. Group I Unrestrained with an occupant load greater than 50, not having surgery or emergency treatment facilities. 5. Group I Restrained. 6. Power generating stations and other public utility facilities not included in Group III Seismic Hazard Exposure Group. 7. Any other occupancy with an occupant load greater than 5,000.
Group III Seismic Hazard Exposure Group III buildings are those having essential facilities which are required for postearthquake recovery, including buildings containing any one or more of the indicated uses.	1. Fire or rescue and police stations. 2. Group I Unrestrained having surgery or emergency treatment facilities. 3. Earthquake emergency preparedness centers. 4. Postearthquake recovery vehicle garages. 5. Power generating stations and other utilities required as emergency backup facilities. 6. Primary communication facilities. 7. Highly toxic materials as defined by 308.2.1 as an H4 occupancy where the quantity of the material exceeds the exempt amounts of Table 308.2D.

TABLE 1607.1.8
SEISMIC PERFORMANCE CATEGORIES

EFFECTIVE PEAK VELOCITY-RELATED ACCELERATION, A_v	SEISMIC HAZARD EXPOSURE GROUP		
	I	II	III
$A_v < 0.05$	A	A	A
$0.05 \leq A_v < 0.10$	B	B	C
$0.10 \leq A_v < 0.15$	C	C	C
$0.15 \leq A_v < 0.20$	C	D	D
$0.20 \leq A_v$	D	D	E

TABLE 1607.3.1
SITE COEFFICIENT

SOIL PROFILE TYPE	DESCRIPTION	SITE COEFFICIENT S
S_1	A soil profile with either: Rock of any characteristic, either shale-like or crystalline in nature, which has a shear wave velocity greater than 2,500 feet per second or Stiff soil conditions where the soil depth is less than 200 feet and the soil types overlaying rock are stable deposits of sands, gravels or stiff clays.	1.0
S_2	A soil profile with deep cohesionless or stiff clay conditions, where the soil depth exceeds 200 feet and soil types overlaying rock are stable deposits of sands, gravels, or stiff clays.	1.2
S_3	A soil profile containing 20 to 40 ft in thickness of soft to medium-stiff clays with or without intervening layers of cohesionless soils.	1.5
S_4	A soil profile characterized by a shear wave velocity of less than 500 feet per second containing more than 40 ft of soft clay.	2.0

TABLE 1607.3.3[1]
STRUCTURAL SYSTEMS

BASIC STRUCTURAL SYSTEM	RESPONSE MODIFICATION FACTOR	DEFLECTION AMPLIFICATION FACTOR	STRUCTURAL SYSTEM LIMITATIONS AND BUILDING HEIGHT (ft) LIMITATIONS[2]			
			Seismic Performance Category			
Seismic resisting system	R	C_d	A & B	C	D[4]	E[5]
BEARING WALL SYSTEM						
Light framed walls w/shear panels	6 1/2	4	NL	NL	160	100
Reinforced concrete shear walls	4 1/2	4	NL	NL	160	100
Reinforced masonry shear walls	3 1/2	3	NL	NL	160	100
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Unreinforced masonry shear walls	1 1/4	1 1/4	NL	Note 3	NP	NP
Plain Concrete Shear Walls	1 1/2	1 1/2	NL	Note 3	NP	NP
BUILDING FRAME SYSTEM						
Eccentrically braced frames, moment resisting connections at columns away from link beam	8	4	NL	NL	160	100
Eccentrically braced frames, non-moment resisting connections at columns away from link beam	7	4	NL	NL	160	100
Light framed walls with shear panels	7	4 1/4	NL	NL	160	100
Concentrically braced frames	5	4 1/2	NL	NL	160	100
Reinforced concrete shear walls	5 1/2	5	NL	NL	160	100
Reinforced masonry shear walls	4 1/2	4	NL	NL	160	100
Unreinforced masonry shear walls	1 1/2	1 1/2	NL	Note 3	NP	NP
Plain Concrete Shear Walls	2	2	NL	Note 3	NP	NP
MOMENT RESISTING FRAME SYSTEM						
Special moment frames of steel	8	5 1/2	NL	NL	NL	NL
Special moment frames of reinforced concrete	8	5 1/2	NL	NL	NL	NL
Intermediate moment frames of reinforced concrete	5	4 1/2	NL	NL	NP	NP
Ordinary moment frames of steel	4 1/2	4	NL	NL	160	100
Ordinary moment frames of reinforced concrete	3	2 1/2	NL	NP	NP	NP

TABLE 1607.4.1.2
COEFFICIENT FOR UPPER LIMIT ON CALCULATED PERIOD, C_a

A_v COEFFICIENT REPRESENTING EFFECTIVE PEAK VELOCITY-RELATED ACCELERATION	C_a
0.4	1.2
0.3	1.3
0.2	1.4
0.15	1.5
0.1	1.7
0.05	1.7